SunShot Concentrating Solar Power Program Update

Ranga Pitchumani

Program Review Meeting • April 23, 2013 • Phoenix, AZ

SunShot
U.S. Department of Energy

Concentrating Solar Power Team

CSP Director

Ranga Pitchumani

Technology Development Managers

- Jesse Gary
- Levi Irwin
- Mark Lausten
- Joseph Stekli
- Andru Prescod

Fellows

- Candace Pfefferkorn
- Edward Hoegg
- Anna Brockway

Technical Project Officers

- Thomas Rueckert
- Christine Bing

Finance and Program Support

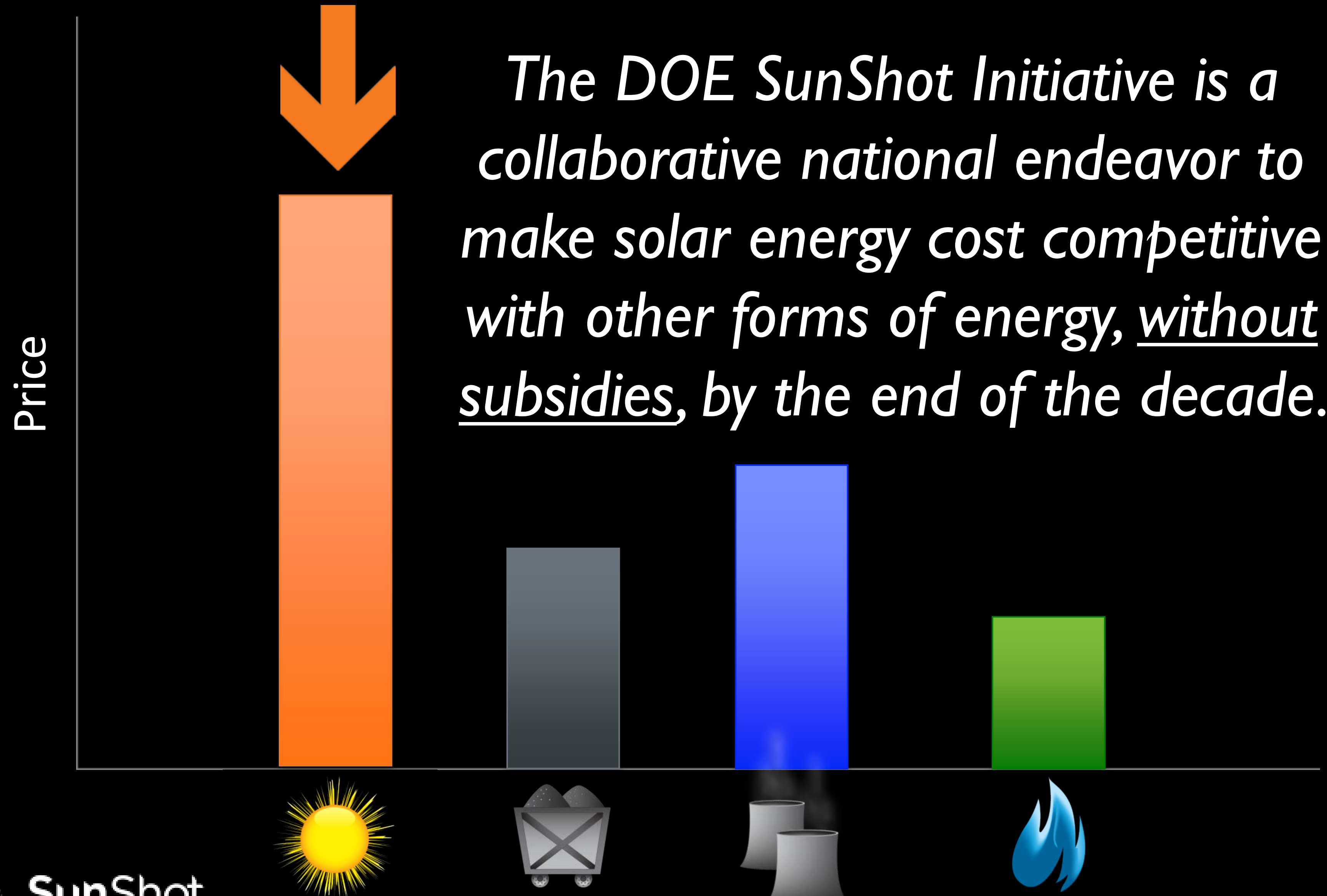
- Jason Plageman
- Page Christensen
- Allison Pezzullo

Communications

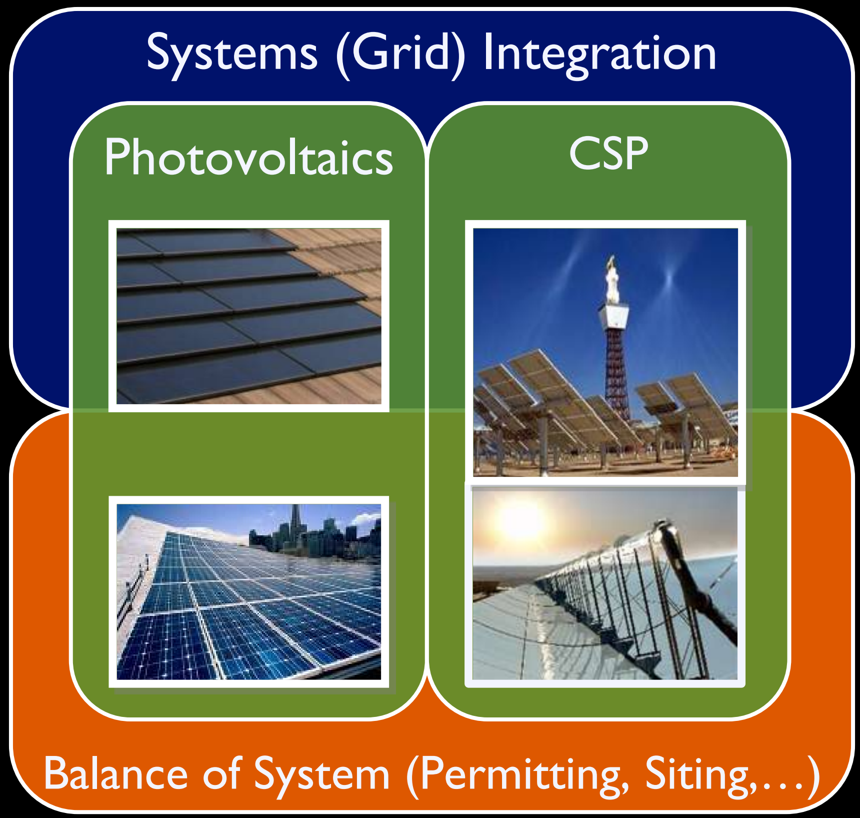
Linh Truong

SunShot Initiative

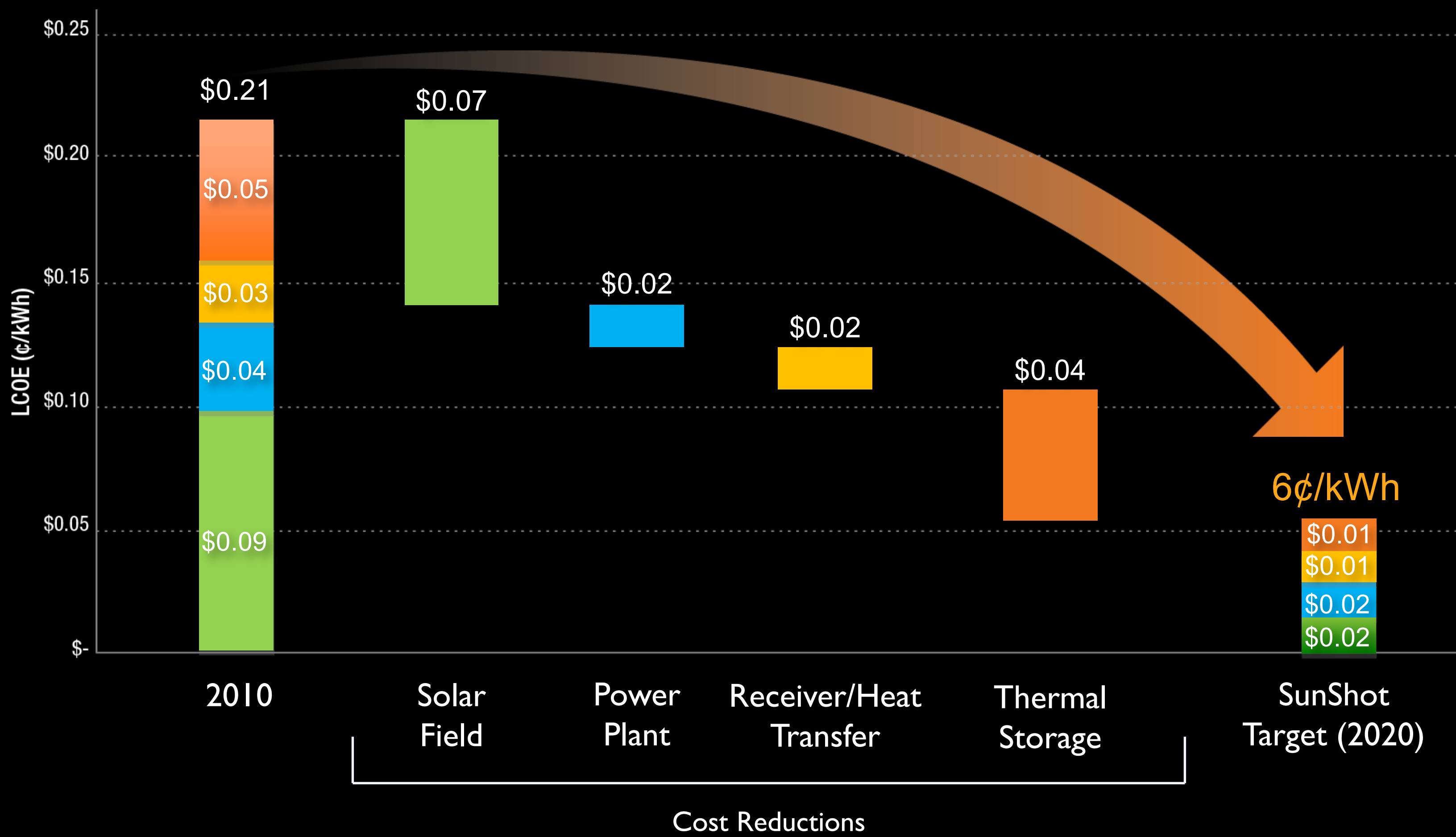
The DOE SunShot Initiative is a collaborative national endeavor to make solar energy cost competitive with other forms of energy, without subsidies, by the end of the decade.



SunShot Program Structure



SunShot Goal



SunShot U.S. Department of Energy

Deconstructing 6¢/kWh

BRIDGE
(2012; Receiver)

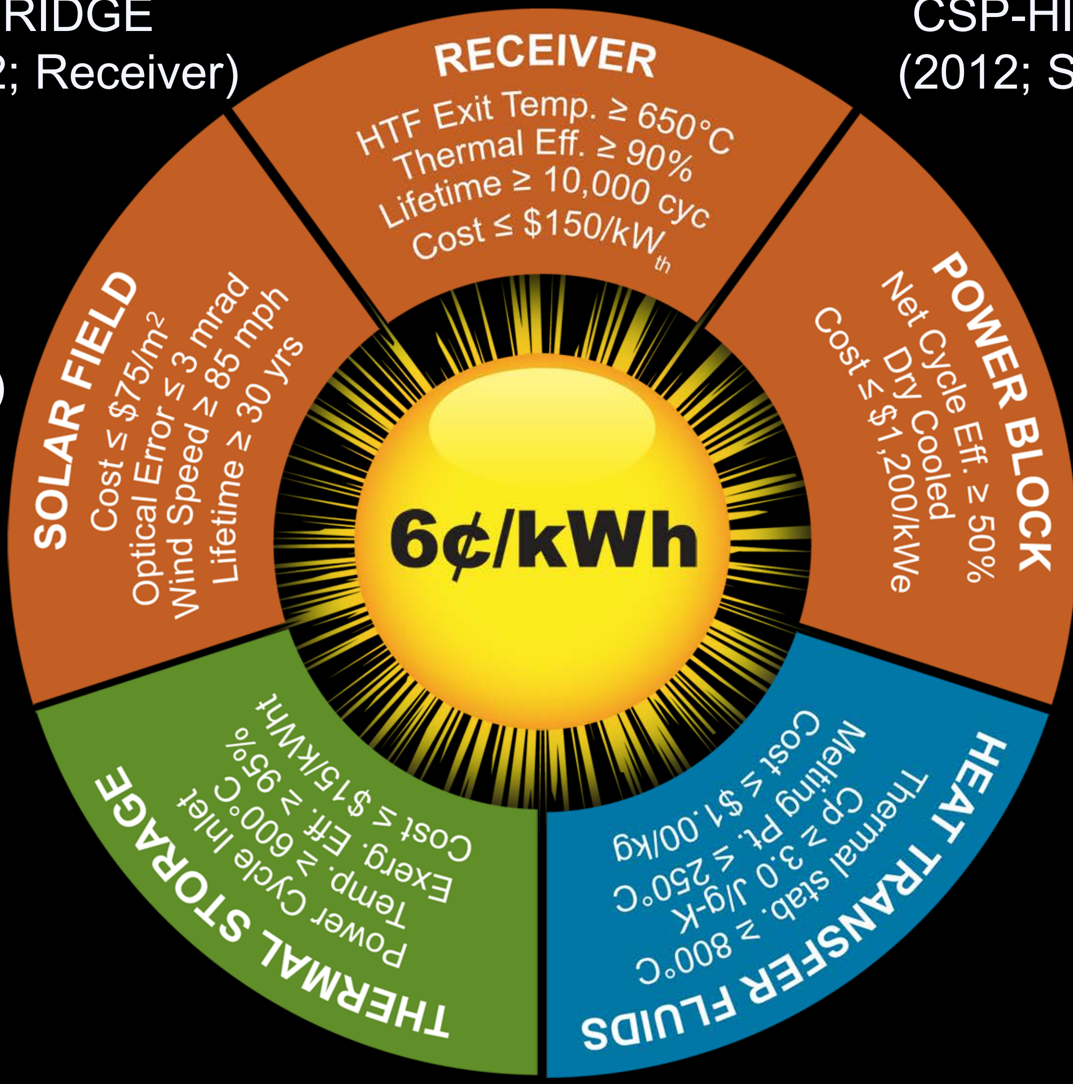
CSP-HIBRED
(2012; System)

SolarMat
(2013; Solar Field)

PREDICTS
(2013; All)

SunShot Incubator
(2012, 2013
Storage; Collector)

National Lab R&D
(2012; All)



SunShot
U.S. Department of Energy

Ongoing Programs

SunShot CSP FOA Awards

- Goal: To innovate and develop next-generation CSP technologies for low-cost collectors, high-temperature receivers and high-efficiency dry-cooled power cycles to meet the aggressive technical targets of SunShot.
- Investment: Up to $55 million over 3 years in 21 projects at companies, universities and national laboratories.

Collectors

3M
Boston University
BrightSource
The University of Arizona
Thermata
JPL Jet Propulsion Laboratory
PennState

Receivers

Argonne National Laboratory
San Diego State University
OSU Oregon State University
UC San Diego
NREL
Norwich Technologies
Sandia National Laboratories
Brayton Energy

Power Cycles

MIT Massachusetts Institute of Technology
NREL
SwRI
SLAC
Stanford University
Pacific Northwest National Laboratory
SwRI

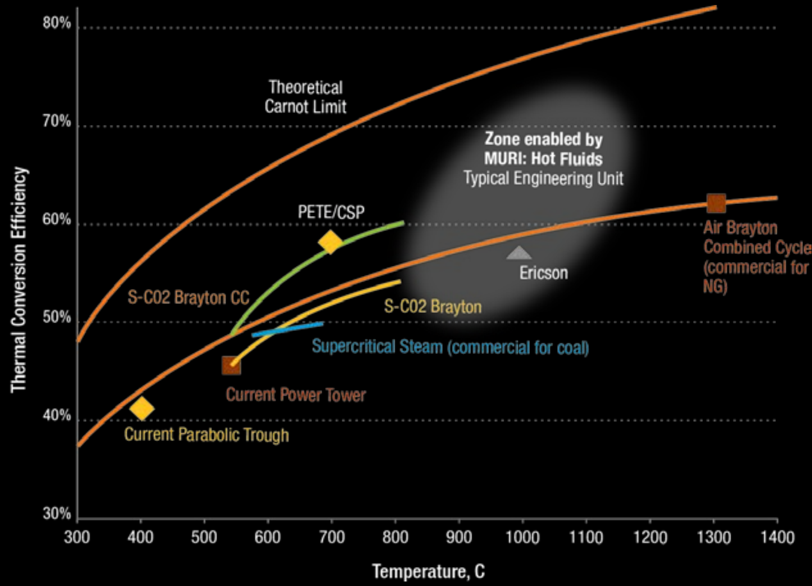
CSP National Lab R&D Funding

- Investment: 12 projects at national laboratories.
- This is additional investment in the national laboratories on top of their awards through the competitive FOAs
- Lab funding is broad based, with technologies applicable to all CSP Systems and spanning near-term to long-term research.

NREL	4 Projects	Los Alamos National Laboratory EST. 1943	1 Project Each
Sandia National Laboratories	3 Projects	Oak Ridge National Laboratory	
SRNL Savannah River National Laboratory	2 Projects	Argonne National Laboratory	

MURI HOT Fluid FOA Awards

- Goal: To develop high operating temperature HTF (> 650˚C; Liquidus range: 0 – 1300˚C; properties ≥ solar salt; thermodynamic cycles with ≥ 50% efficiency).
- Investment: Up to $10.5 million over 5 years in 2 projects at universities.
- Over 40 different universities competed as 11 teams, of which two teams were selected…



Liquid Metals

UCLA
University of California
Yale University

Molten Salts

The University of Arizona
Georgia Tech
ASU Arizona State University

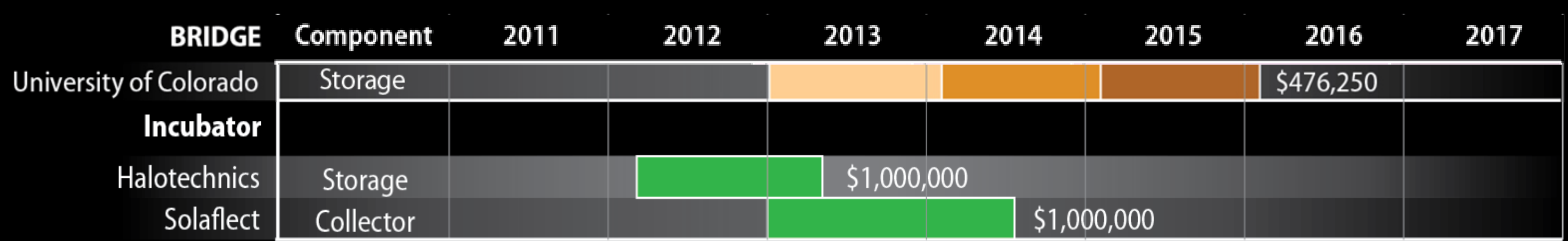
Cross-Program Initiatives

Bridging Research Interactions through collaborative Development Grants in Energy (BRIDGE 2012)

- *Support Collaborative Research Teams (CRTs) that leverage existing DOE Basic Energy Sciences (BES) Scientific User Facilities and Advanced Scientific Computing Research facilities (ASCR)*
- *Up to $9M, 3 yr awards, 20% cost*

Incubator

- *Funds hardware and software solutions to move them from an alpha or lab-scale prototype to a commercial product or business.*
- *Up to $12M total DOE funding over FY13 to FY14*
- **<u>History of success</u>:** *~$92M in DOE funds since 2007 helped leverage over $1.7B in private sector funds*



Pre-SunShot and ARPA-E Programs

CSP R&D (2007)

- Incentivize U.S. manufacturers to invest in CSP technology
- $35M total DOE funding
- 12 Industry awards

CSP Thermal Storage (2008)

- Generate novel thermal energy storage (TES) concepts
- $27M total DOE funding
- 15 awards: 9 Industry, 6 University

ARRA Projects (2009)

- Develop new TES systems and HTF
- Upgrade NREL and Sandia facilities
- Dismantle Solar Two
- $29M total DOE funding
- 9 awards: 1 Industry, 8 National

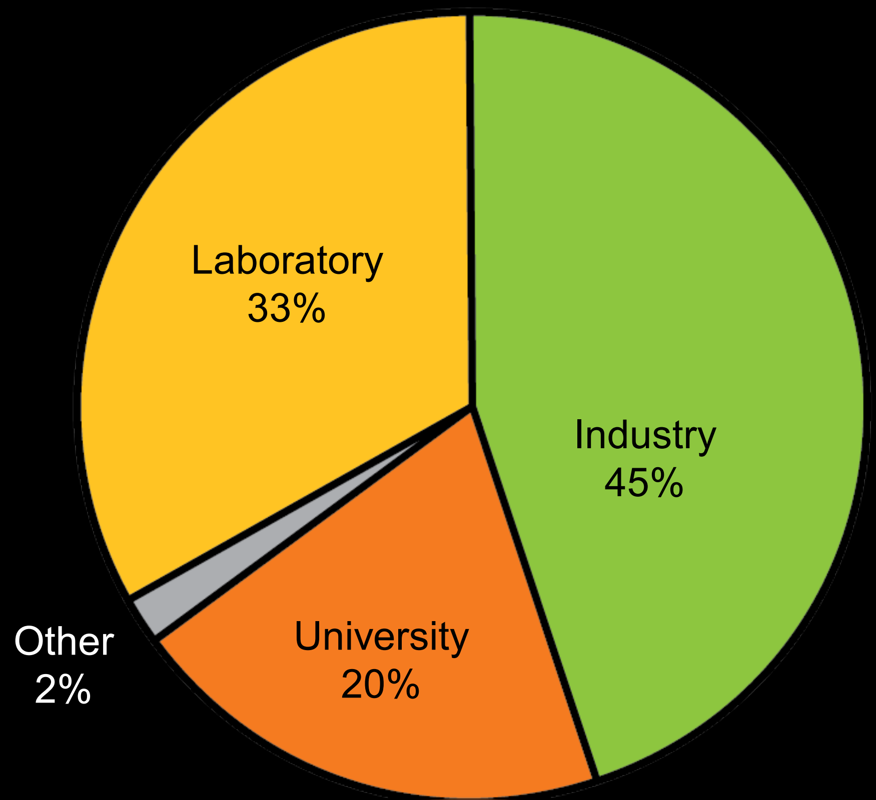
CSP Baseload (2010)

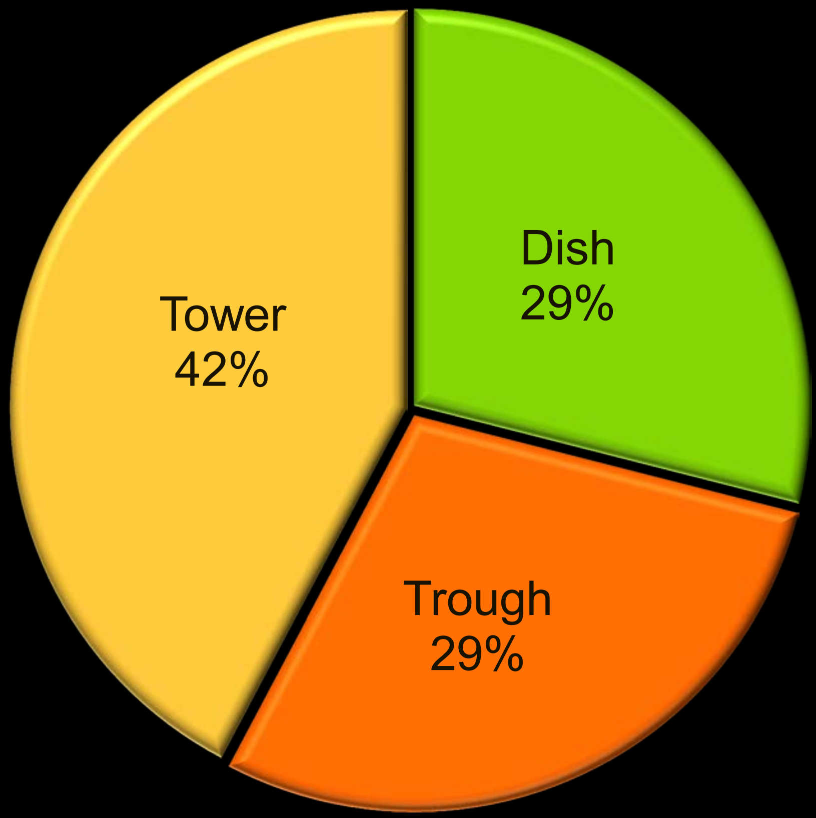
- Develop CSP baseload systems with capacity factor: >75%; Size: >100 MW; LCOE: <8-9¢/kWh (adjusted 6¢/kWh)
- $53M total DOE funding
- 13 awards: 12 Industry, 1 University

ARPA-E Programs

- HEATS (High Energy Advanced Thermal Storage): Thermal Energy Storage (2011)
- ARPA-E Open FOA (2010 and 2012)

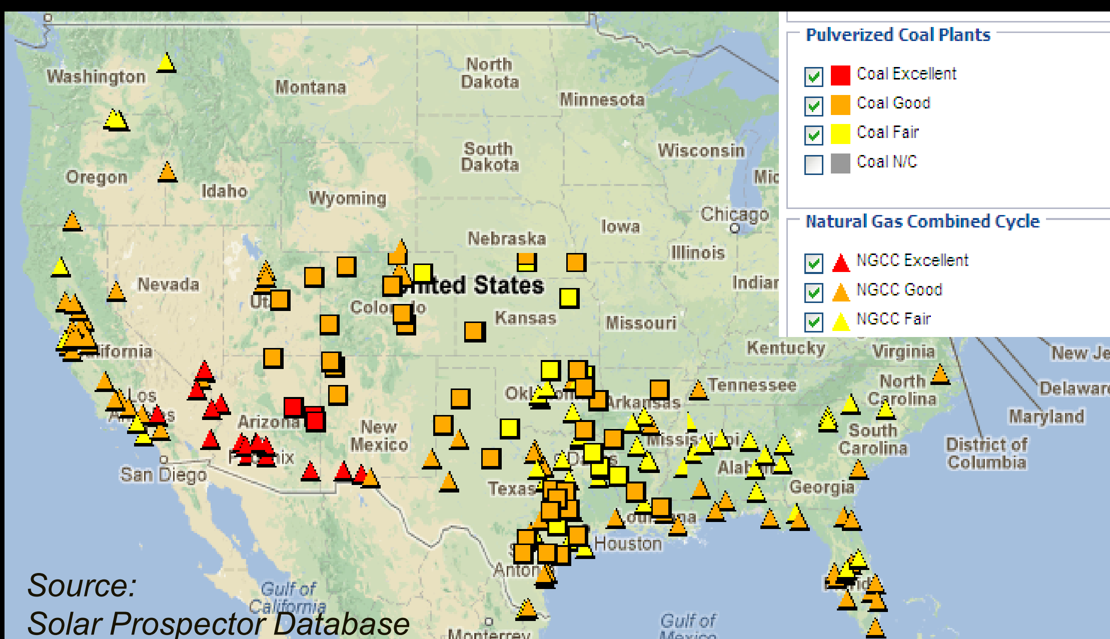
FY12 CSP Funding Distribution





FY13 Funding Opportunities

CSP Heat Integration for Baseload Renewable Energy Development (CSP-HIBRED 2013)



- 11-21 GW of U.S. fossil plants available for CSP hybridization
- CSP HIBRED FOA seeks to catalyze CSP-fossil hybrid deployment to take advantage of this opportunity
- <u>Goal</u>: Validate 10 ¢/kWh solar electricity generation with long term project financial sustainability
- $20M total DOE funding
- 3:1 Awardee Cost share (75%
- Anticipate 2-4 awards
  - ~20 MW solar to be built
  - Max. award $10 M DOE
  - Min. 1 MWe solar

Solar Manufacturing Technology (SolarMat 2013)

- Goal
  - CSP: Achieve an installed solar field cost of <$75/m^2 (>50% reduction from current cost) while reducing field construction time by 75% (~2 years for a 250MW plant down to 6 months).
- 2 Topics (PV & CSP)
- $15M total DOE funding
- 1:1 Awardee Cost share (50%) to DOE funds
- Approximately 2-4 awards
  - 1-2 from each topic area
  - Maximum award $5 M DOE

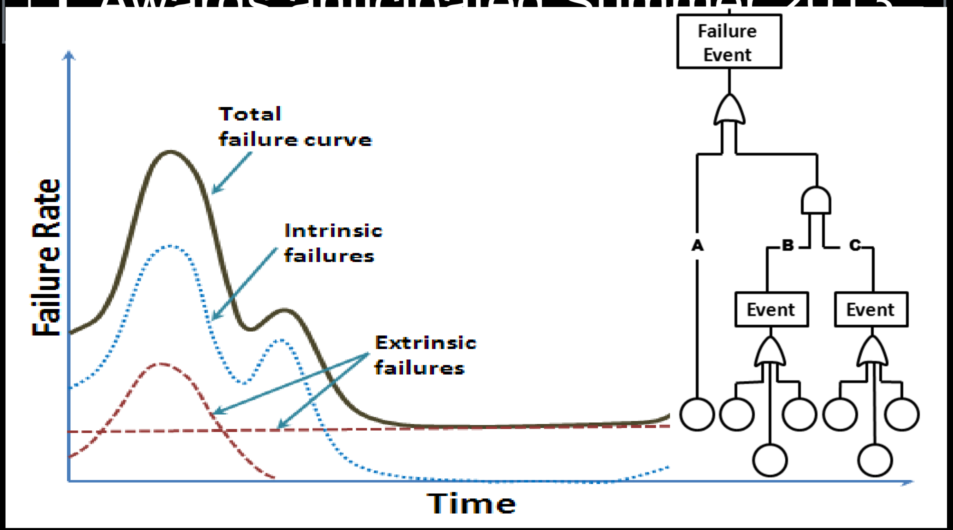
Physics of Reliability: Evaluating Design Insights for Component Technologies in Solar (PREDICTS 2013)

Objectives

1. Current reliability analysis focuses largely on correlation not causation
2. Physics-based predictive models for CSP and PV components or sub-systems will improve design for reliable performance in service
3. Improve product bankability through reduced risk
4. Increased reliability of solar electricity generation

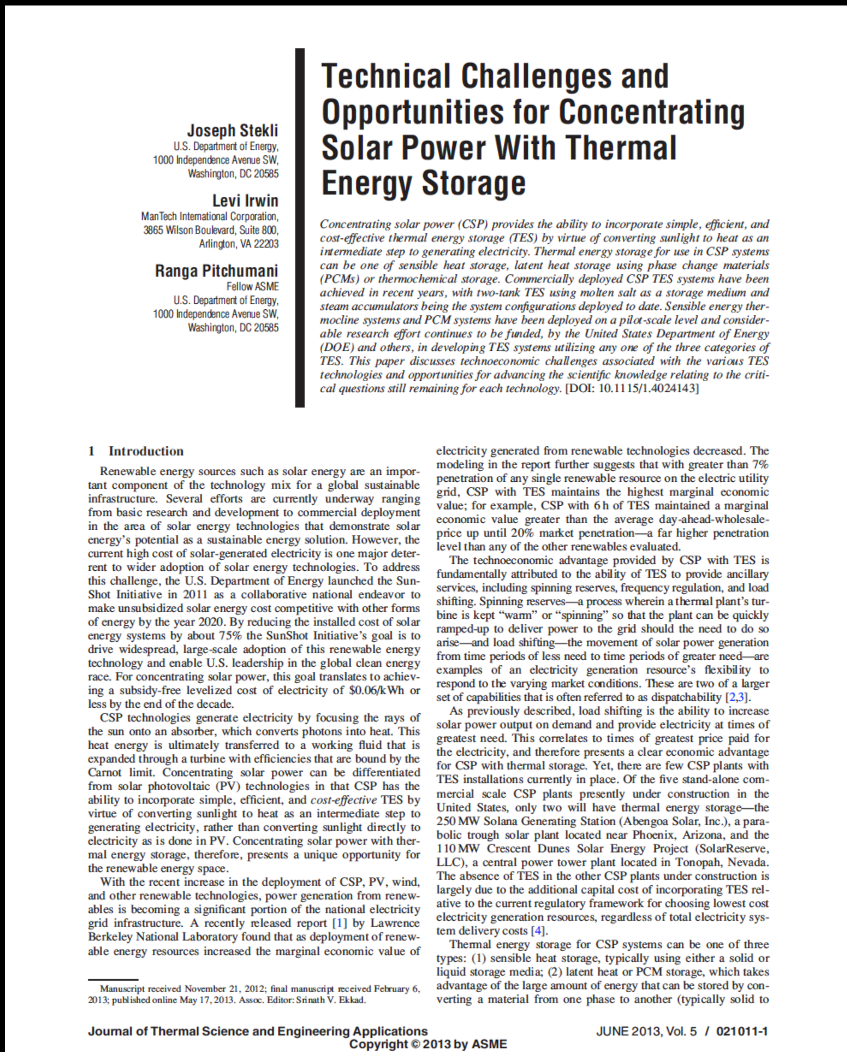
Project Details

- ❑ Cross cutting program: CSP, PV, and Systems Integration (microinverters)
- ❑ Up to $5M total DOE funding over 3 years (20% cost share)
- ❑ Released February 2013
- ❑ Awards anticipated Summer 2013



SunShot
U.S. Department of Energy

Thermal Energy Storage



Technical Challenges and Opportunities for Concentrating Solar Power With Thermal Energy Storage

Joseph Stekli
U.S. Department of Energy,
1000 Independence Avenue SW,
Washington, DC 20585

Levi Irwin
ManTech International Corporation,
3865 Wilson Boulevard, Suite 800,
Arlington, VA 22203

Ranga Pitchumani
Fellow ASME
U.S. Department of Energy,
1000 Independence Avenue SW,
Washington, DC 20585

Concentrating solar power (CSP) provides the ability to incorporate simple, efficient, and cost-effective thermal energy storage (TES) by virtue of converting sunlight to heat as an intermediate step to generating electricity. Thermal energy storage for use in CSP systems can be one of sensible heat storage, latent heat storage using phase change materials (PCMs) or thermochemical storage. Commercially deployed CSP TES systems have been achieved in recent years, with two-tank TES using molten salt as a storage medium and steam accumulators being the system configurations deployed to date. Sensible energy thermocline systems and PCM systems have been deployed on a pilot-scale level and considerable research effort continues to be funded, by the United States Department of Energy (DOE) and others, in developing TES systems utilizing any one of the three categories of TES. This paper discusses technoeconomic challenges associated with the various TES technologies and opportunities for advancing the scientific knowledge relating to the critical questions still remaining for each technology. [DOI: 10.1115/1.4024143]

1 Introduction

Renewable energy sources such as solar energy are an important component of the technology mix for a global sustainable infrastructure. Several efforts are currently underway ranging from basic research and development to commercial deployment in the area of solar energy technologies that demonstrate solar energy's potential as a sustainable energy solution. However, the current high cost of solar-generated electricity is one major deterrent to wider adoption of solar energy technologies. To address this challenge, the U.S. Department of Energy launched the SunShot Initiative in 2011 as a collaborative national endeavor to make unsubsidized solar energy cost competitive with other forms of energy by the year 2020. By reducing the installed cost of solar energy systems by about 75% the SunShot Initiative's goal is to drive widespread, large-scale adoption of this renewable energy technology and enable U.S. leadership in the global clean energy race. For concentrating solar power, this goal translates to achieving a subsidy-free levelized cost of electricity of $0.06/kWh or less by the end of the decade.

CSP technologies generate electricity by focusing the rays of the sun onto an absorber, which converts photons into heat. This heat energy is ultimately transferred to a working fluid that is expanded through a turbine with efficiencies that are bound by the Carnot limit. Concentrating solar power can be differentiated from solar photovoltaic (PV) technologies in that CSP has the ability to incorporate simple, efficient, and *cost-effective* TES by virtue of converting sunlight to heat as an intermediate step to generating electricity, rather than converting sunlight directly to electricity as is done in PV. Concentrating solar power with thermal energy storage, therefore, presents a unique opportunity for the renewable energy space.

With the recent increase in the deployment of CSP, PV, wind, and other renewable technologies, power generation from renewables is becoming a significant portion of the national electricity grid infrastructure. A recently released report [1] by Lawrence Berkeley National Laboratory found that as deployment of renewable energy resources increased the marginal economic value of electricity generated from renewable technologies decreased. The modeling in the report further suggests that with greater than 7% penetration of any single renewable resource on the electric utility grid, CSP with TES maintains the highest marginal economic value; for example, CSP with 6 h of TES maintained a marginal economic value greater than the average day-ahead-wholesale-price up until 20% market penetration—a far higher penetration level than any of the other renewables evaluated.

The technoeconomic advantage provided by CSP with TES is fundamentally attributed to the ability of TES to provide ancillary services, including spinning reserves, frequency regulation, and load shifting. Spinning reserves—a process wherein a thermal plant's turbine is kept "warm" or "spinning" so that the plant can be quickly ramped-up to deliver power to the grid should the need to do so arise—and load shifting—the movement of solar power generation from time periods of less need to time periods of greater need—are examples of an electricity generation resource's flexibility to respond to the varying market conditions. These are two of a larger set of capabilities that is often referred to as dispatchability [2,3].

As previously described, load shifting is the ability to increase solar power output on demand and provide electricity at times of greatest need. This correlates to times of greatest price paid for the electricity, and therefore presents a clear economic advantage for CSP with thermal storage. Yet, there are few CSP plants with TES installations currently in place. Of the five stand-alone commercial scale CSP plants presently under construction in the United States, only two will have thermal energy storage—the 250 MW Solana Generating Station (Abengoa Solar, Inc.), a parabolic trough solar plant located near Phoenix, Arizona, and the 110 MW Crescent Dunes Solar Energy Project (SolarReserve, LLC), a central power tower plant located in Tonopah, Nevada. The absence of TES in the other CSP plants under construction is largely due to the additional capital cost of incorporating TES relative to the current regulatory framework for choosing lowest cost electricity generation resources, regardless of total electricity system delivery costs [4].

Thermal energy storage for CSP systems can be one of three types: (1) sensible heat storage, typically using either a solid or liquid storage media; (2) latent heat or PCM storage, which takes advantage of the large amount of energy that can be stored by converting a material from one phase to another (typically solid to

Manuscript received November 21, 2012; final manuscript received February 6, 2013; published online May 17, 2013. Assoc. Editor: Srinath V. Ekkad.

- Thermal energy storage is a distinguishing feature of Concentrating Solar Power
- A summary of various approaches and the associated challenges and opportunities relative to the SunShot goals is presented in a peer-reviewed ASME journal article to be published in June 2013

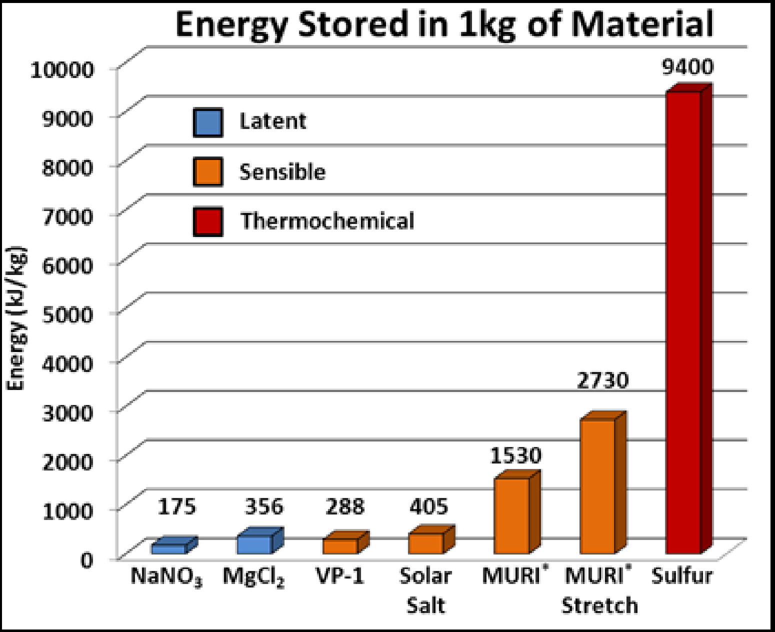
ASME Journal of Thermal Science and Engineering Applications, Vol. 5, Paper No. 021011, 12pp., 2013

http://dx.doi.org/10.1115/1.4024143

SunShot
U.S. Department of Energy

Storing Sun's Energy in Chemical Bonds:

Thermochemical Energy Storage for Concentrating Solar Power



Chemical Energy Density >> Sensible, Latent Energy Densities

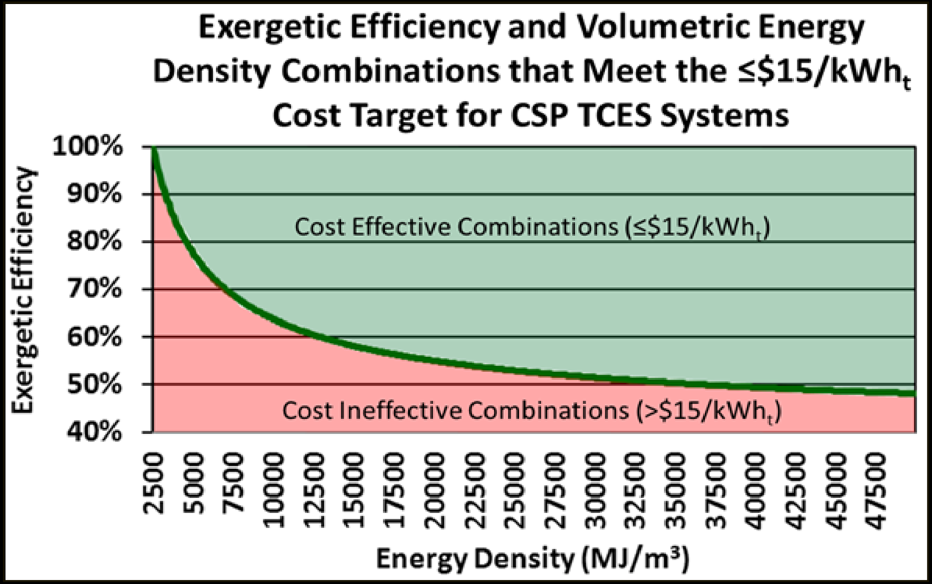
1. Can we engineer CSP integrated energy storage based on chemical reactions to capture and release energy on demand?

2. Can we do so in a cost-effective manner with high efficiency to meet the SunShot goals?

CSP:ELEMENTS

Concentrating Solar Power: Efficiently Leveraging Equilibrium Mechanisms for Engineering New Thermochemical Storage

- The FOA seeks to develop and demonstrate TCES systems that
  - meet the SunShot cost target of < $15/kWh_{th}$ and
  - the minimum exergetic efficiency for the volumetric energy density specified.



- FOA Structure
  - Topic 1: Applications for complete TCES systems that address all 8 "Areas of Focus". Projects result in an on-sun demonstration (100-500kW$_{th}$).
  - Topic 2: Seedling applications address only one or a few of the Areas of Focus.

Areas of Focus for TCES Systems	
Efficiency Maximization	Process Engineering
Reactor Engineering	Heat and Mass Transfer
Catalysis	System Modeling
Materials of Construction	On-Sun Testing

SunShot U.S. Department of Energy

CSP:ELEMENTS

Concentrating Solar Power: Efficiently Leveraging Equilibrium Mechanisms for Engineering New Thermochemical Storage

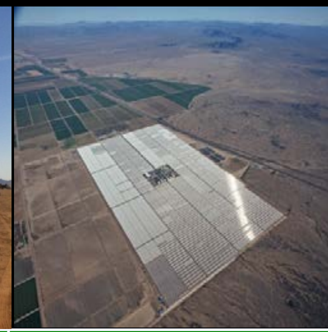
- FOA Number: DE-FOA-0000805
- $20M DOE Investment (20% Cost Share)
- Approximately 8-24 awards
  - Topic 1 Maximum award $4 M DOE; Minimum $1M DOE
  - Topic 2 Maximum award $1 M DOE; Minimum $0.5M DOE
- Key Dates:

Issue date:	April 23, 2013
Concept papers due:	May 23, 2013
Full applications due:	July 23, 2013
Selection notifications (tentative):	September 23, 2013

CSP Deployment

CSP Plants Under Construction in the US





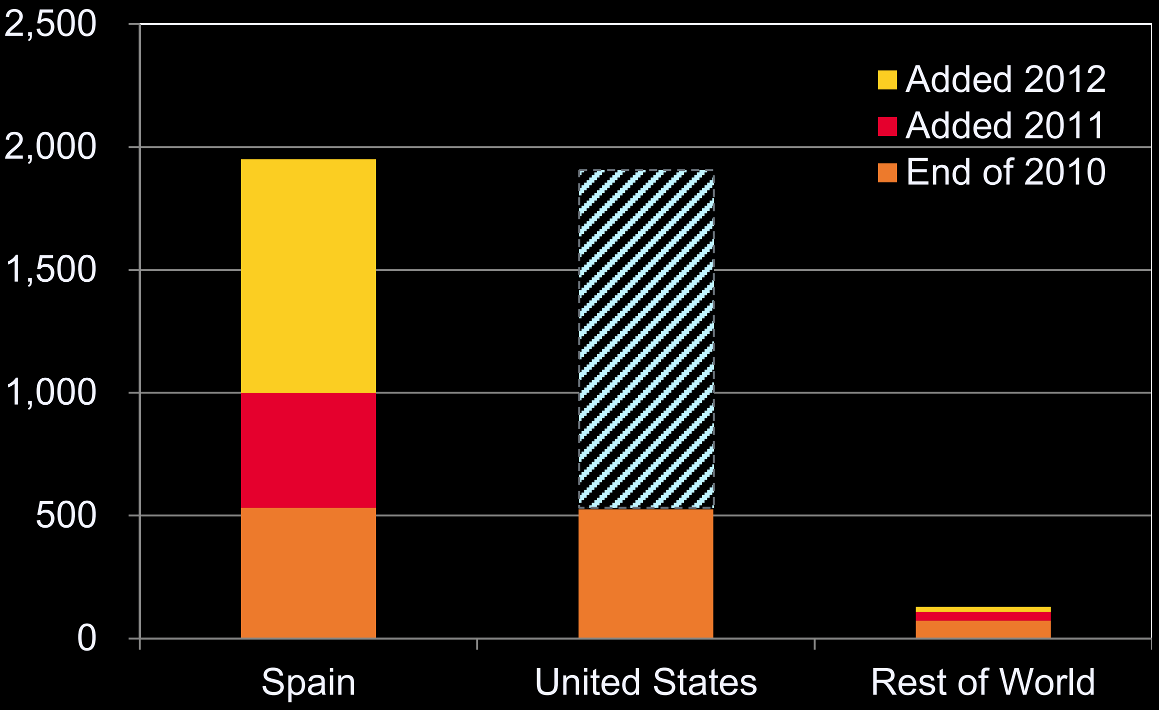
Project	Ivanpah	Genesis	Solana	Crescent Dunes	Mojave
Utility	SCE + PG&E	PG&E	APS	NVE	PG&E
State	California	California	Arizona	Nevada	California
Size	392 MW	250 MW	280 MW	110 MW	280 MW
Technolog y	Power Tower	Trough	Trough/ Storage	Power Tower/Storage	Trough
COD	2013	2013-2014	2013	2014	2014
DOE Loan	$1.63 B	$0.85 B	$1.45 B	$.74 B	$1.2 B
Company	BrightSource	NextEra	Abengoa	SolarReserve	Abengoa

Total CSP under construction: 1,312 MW

March 15, 2013: Abengoa and BrightSource announced a joint venture to build the 500 MW Palen Solar Complex. Start 2013; COD: 2016

SunShot
U.S. Department of Energy

Global CSP Installations (MW)

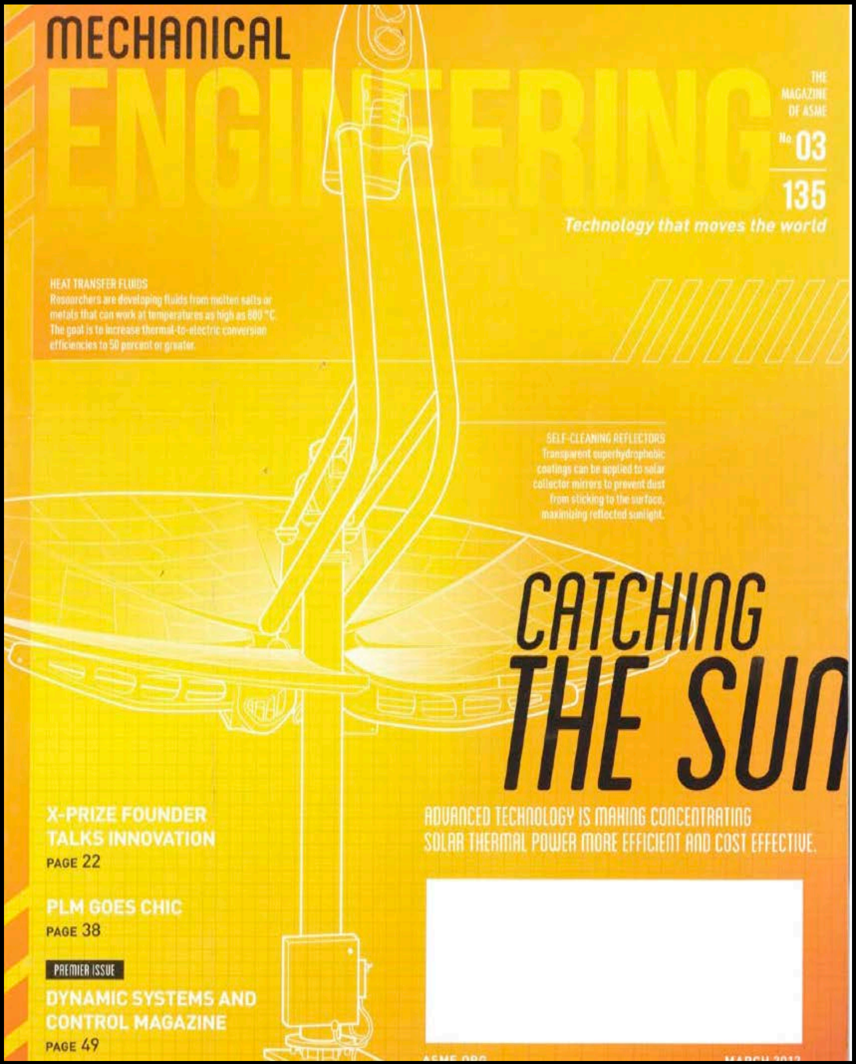


	End of 2010	Added 2011	Added 2012	End of 2012
Spain	532.0	467.0	951.0	1,950.0
United States	525.0			525.0
Algeria		25.0		25.0
Egypt	20.0			20.0
Morocco	20.0			20.0
Iran	17.0			17.0
Chile			10.0	10.0
Australia	3.0		6.3	9.3
Israel	6.0			6.0
India		2.5	3.0	5.5
Italy	5.0			5.0
Thailand		5.0		5.0
China		1.0	1.0	2.0
France		1.0	1.0	2.0
Germany	1.5			1.5
Denmark			0.5	0.5
South Korea		0.2		0.2
Total	1,129.5	501.7	972.8	2,604.0

SunShot U.S. Department of Energy

SunShot CSP Outreach

SunShot CSP in the News



The New York Times

April 10, 2013

New Solar Process Gets More Out of Natural Gas

By MATTHEW L. WALD

WASHINGTON — The Energy Department is preparing to test a new way for solar power to make electricity: using the sun's heat to increase the energy content of natural gas.

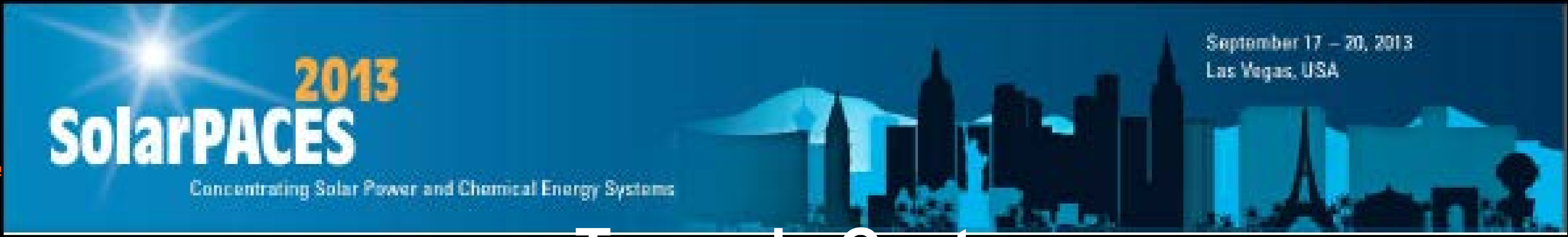
Researchers at the Pacific Northwest National Laboratory in Richland, Wash., hope by this summer to carry out the test, which entails a process that could cut the amount of natural gas used — and the greenhouse gasses emitted — by 20 percent.

"We can reduce carbon dioxide emissions, and the consumer doesn't get hit," said Robert Wegeng, the researcher in charge of the project.

The system is a marriage of chemical engineering and mechanical engineering. The process will work anywhere it is sunny, according to researchers, although it might be more valuable in places where natural gas is relatively expensive, or where a company making electricity would be paid for generating less carbon dioxide.

http://nyti.ms/14tz5lj

http://www.asme.org/kb/news---articles/articles/renewable-energy/catching-the-sun



Towards Cost-competitive CSP

- 3.5 days of technical sessions + Tours of Ivanpah and Crescent Dunes.
- 520 Abstracts Received (most ever)
- www.solarpaces2013.solarpaces.org

DOE SunShot CSP Symposium at the ASME Energy Sustainability Conference

- Goal: To share the SunShot objectives and developments with the broader community as well as to have the community at large addressing the SunShot goals.
- Initiated in 2012 with 3 sessions, extremely popular and well attended.
- A full day Symposium at the 2013 conference in Minneapolis (July 2013).

SunShot
U.S. Department of Energy

Program Review Meeting Schedule

- Plenary Sessions
  - Keynote talks
    - *Value of CSP with Storage (Denholm, NREL)*
    - *Financing CSP in Emerging Markets (Younger, IFC–World Bank Group)*
    - *Integrating CSP with TES in a Utility System (Albert, APS)*
  - Highlight talks
    - *eSolar (Tyner); 3M (Chen); Abengoa (Price)*
- Technical Sessions
  - Two parallel tracks
- Banquet (Wednesday)
- Solana Plant Tour (Thursday afternoon)

Ranga Pitchumani
Director, Concentrating Solar Power
ranga.pitchumani@ee.doe.gov
www.solar.energy.gov/sunshot/csp.html